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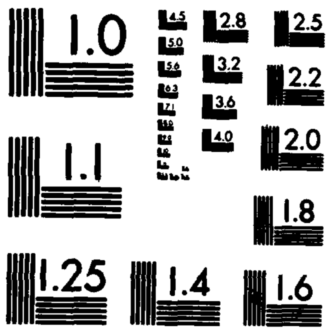
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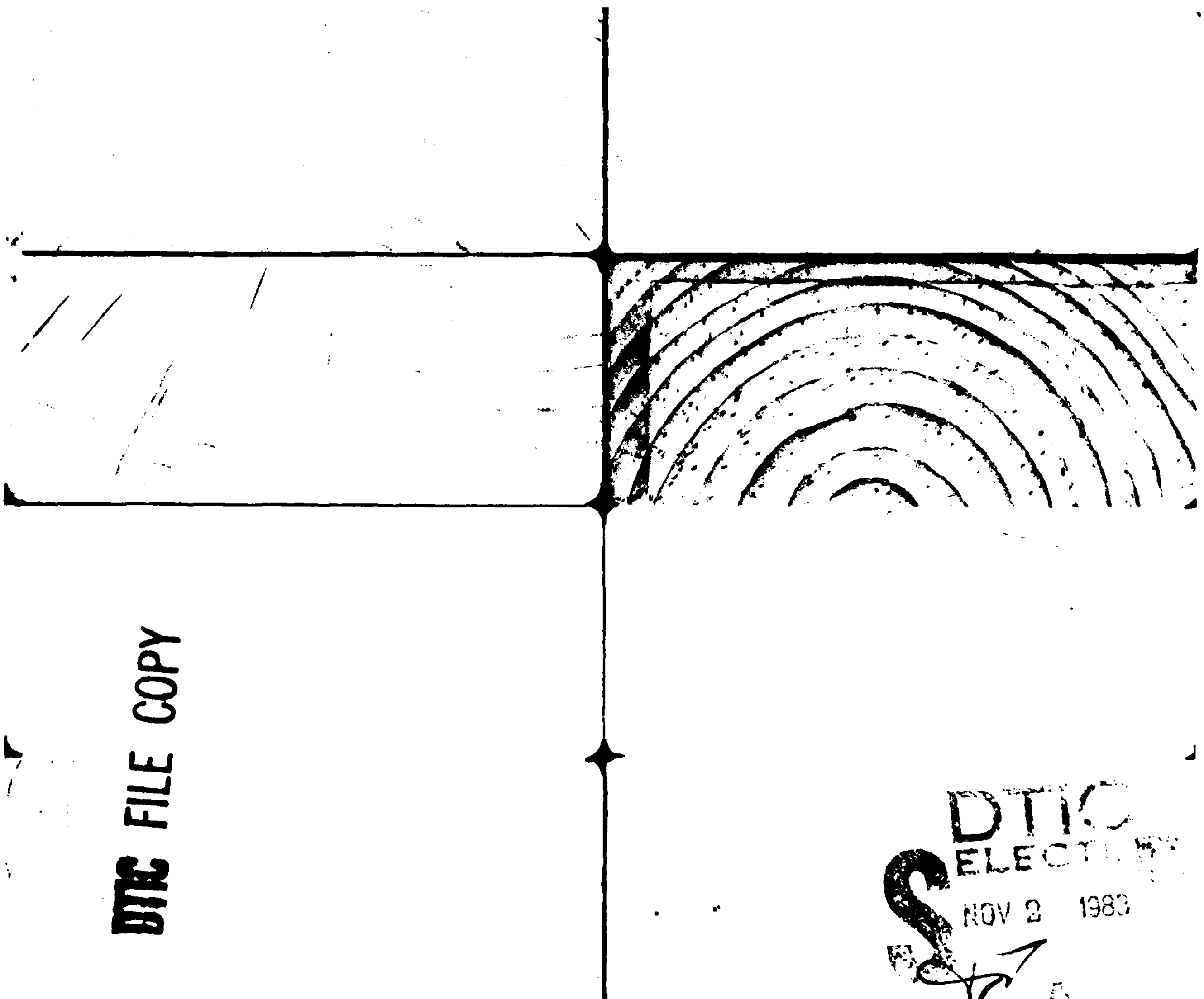
Characterization of Physical and Mechanical Properties of 2 by 4 Truss Lumber

C. C. Gerhards



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Abstract

This paper summarizes data on dimensional characteristics, optimum grade, and regressions of strength on modulus of elasticity and grade class (a function of strength ratio) of lumber specimens sampled from truss fabricators in Illinois. Averages of dimensions, area, section modulus, and moment of inertia of the nominal 2- by 4-inch specimens at 12 percent moisture content were very close to those for standard dimensions (1.5 by 3.5 in.); distributions of those properties tended to be skewed toward lower values. Mill grading of the lumber specimens was generally conservative compared to optimum grade levels based on the National Grading Rule. Regressions of strength in compression, tension, or bending on an edgewise short-span modulus of elasticity appeared to be adequate for strength prediction or for machine stress rating. The two or three measures of bending strength at different positions in a specimen showed low correlation, suggesting that bending strength at one position in a specimen can be quite different from that at another position. This report, along with a previous report, provides a strength data base for engineering evaluation of wood truss reliability. The data on species, grade, and dimensions should be of interest to grading agencies and code groups.

Nomenclature

A,B	Regression coefficients
ASTM	American Society for Testing and Materials
COV	Coefficient of Variation
E	Modulus of elasticity
EB	Bending E
EC	Compressive E
EF	Full-Span E
ER	E-Ratio
ESP	Short-Span E
ESPH	Highest ESP per cord
ESPL	Minimum ESP per cord
ET	Tensile E
GC	Grade class
KD	Kiln dry
NGR	National Grading Rule
S-DRY	Surfaced dry
S-GRN	Surfaced green

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Introduction

The modern wood truss, with its metal plate connectors, represents the most highly engineered component in wood-framed houses. Its wide use results from economy and proven performance. Yet, further improvement of the truss may be possible with better understanding of the properties of lumber and of lumber interactions with various components of the structure under real loading conditions.

In late 1975, the Forest Products Laboratory initiated the study reported here to learn more about the properties of lumber used by truss fabricators. The primary purpose of the study was to characterize the engineering properties of truss lumber in a format suitable for others to simulate individual truss strength and variation in strength of consecutive trusses manufactured by a truss fabricator. For the study, nominal 2- by 4-inch lumber, representing the top and bottom chords of 4 consecutive trusses was obtained in 1977 from each of 44 wood truss fabricators located throughout Illinois. Trusses had not actually been built, but the lumber was sampled in a way that the sixteen 2 by 4's per fabricator could have been assembled in four consecutive trusses. Criteria used in obtaining the truss lumber included: 1) The truss fabricator used metal plate connectors that were made by a member of the Truss Plate Institute, 2) lumber had been visually stress graded, and 3) lumber was of a length typical for a 4 in 12 slope W (or Fink) house truss to span 26 feet.

This report deals with physical properties of the lumber (cross sectional), mechanical properties based on actual dimensions at test, correlations of bending strengths within chords, and relationships of strength properties to several nondestructive variables. Other results of the study were reported at the Metal Plate Wood Truss Conference *(4)*[2] in 1979. Those findings are briefly summarized below.

Nineteen different species-group-grade combinations were represented in the 704-piece truss lumber sample. Although predominantly Southern Pine (85%), Douglas Fir-Larch, Hem-Fir, and Spruce-Pine-Fir were also represented. The most common species-grade combination was No. 2 Southern Pine (66% including dense and nondense grades). The highest grade stamp encountered was No. 1, the lowest was Standard. The lumber for each truss was tested for strength in compression, tension, or bending at standard rates *(2)* according to the plan shown in Fig. 1 with the chord orientation chosen by the fabricator. The strength properties and modulus of elasticity (E) were summarized as

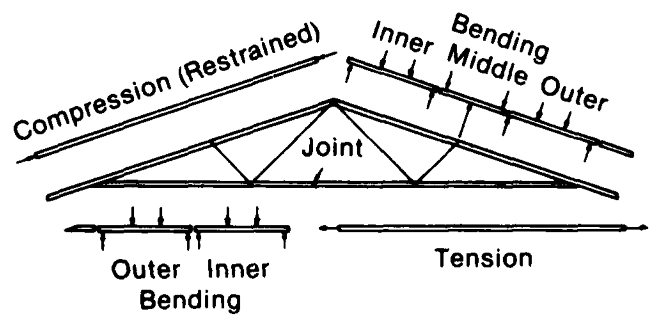

Figure 1.—Schematic of test specimen types for truss chord lumber. Arrows indicate loading modes. (M152111)

[1]The author is a Research General Engineer, Forest Products Laboratory, U.S. Department of Agriculture. The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Underlined numbers in parentheses refer to literature cited at end of this report.

histograms of fabricator averages and coefficients of variation (COV's) based on four trusses per fabricator. All properties were based on standard dimensions assumed for engineered wood structures using 2 by 4's. The average E equaled the weighted average design value *(5)* for all of the species-grade combinations of the truss lumber. The COV of E was 26 percent. Strength properties of the truss lumber averaged 90 percent higher in compression, 110 percent higher in tension, and 160 percent higher in third-point bending than the weighted average design values *(5)* for the species-grade combinations adjusted to a 5-minute test loading condition. However, a few of the 2 by 4's, particularly in tension, had strengths lower than the adjusted design values. More information on standard dimension-based data is available in the conference paper *(4)*.

The data developed in this study differ from that of the "in-grade" testing program *(3)*. The in-grade mechanical property data are based on tests of lumber at sawmills (producers) where moisture content is not equilibrated, whereas the truss lumber data are based on lumber sampled from fabricators (users) and after equilibration at 75° F and 64 percent relative humidity.

This report, along with the conference report, should provide a broad data base for engineering evaluation of truss reliability.

Results

Because of the preponderance of Southern Pine in the sample truss lumber, results are presented in two categories: Southern Pine specimens and all specimens.

Physical Properties

Statistics on moisture content, specific gravity, and cross-sectional properties (table 1) are dominated by Southern Pine, as differences in statistics between the Southern Pine-specimen category and the all-specimen category are small. Rather than four chord members per truss, the data on moisture content and specific gravity are based on all seven test specimens per truss (fig. 1)—one compression, one tension, and five bending specimens. Moisture content averaged 12 percent and ranged from 9 to 14 percent, which is common for lumber in equilibrium at 75° F, 64 percent relative humidity. Specific gravity averaged about 0.5 and ranged from 0.33 to 0.86.

Standard dimensions for 2 by 4 lumber are 3.5 inches wide by 1.5 inches thick when surfaced dry (S-DRY), which implies 15 percent average, 19 percent maximum moisture content, or kiln dry (KD) which, for Southern Pine, implies 12 percent average, 15 percent maximum moisture content. Lumber surfaced green (S-GRN) is oversized 1/16 inch in both dimensions to allow for shrinkage. Storage at 75° F, 64 percent RH should have minimal effect on dimensions of KD lumber, but S-DRY or S-GRN lumber can be expected to shrink. All of the Southern Pine lumber had been grade stamped KD. All other lumber had been grade-stamped S-DRY except one 16-specimen sample of Douglas-Fir-Larch which was grade stamped S-GRN.

Lumber width averaged 3.49 inches, very close to standard, and had very small COV (table 1). Width, however, ranged from 5 percent below to 3 percent above standard, and its distribution was skewed to the smaller measurement (fig. 2).

Table 1.—Physical properties of the truss 2 by 4's

Property	Southern Pine					All				
	Number of specimens	Average	COV	Minimum	Maximum	Number of specimens	Average	COV	Minimum	Maximum
			Pct					Pct		
Moisture content (pct)[1]	1,042	12.1	8.8	9.1	14.4	1,230	12.2	8.6	9.1	14.4
Specific gravity[2]	1,042	.51	13.9	.35	.86	1,230	.50	14.4	.33	.86
Width (in.)[3]	596	3.49	1.1	3.34	3.60	704	3.49	1.1	3.34	3.60
Thickness (in.)[3]	596	1.50	1.6	1.42	1.58	704	1.50	1.6	1.40	1.58
Area (in.^{2})	596	5.23	2.3	4.79	5.56	704	5.23	2.3	4.79	5.56
Section modulus (in.^{3})	596	3.05	3.3	2.70	3.29	704	3.05	3.2	2.70	3.29
Moment of inertia (in.^{4})	596	5.33	4.3	4.56	5.90	704	5.32	4.2	4.56	5.90

[1] Ovendry method.

[2] Based on test volume and ovendry weight.

[3] Based on average of measurements at midlength and 2 to 3 feet in from each end of the chord lumber.

Lumber thickness had an average of 1.50 inches and a slightly larger COV than lumber width (table 1), ranging from 7 percent below to 5 percent above standard (fig. 3).

Standard lumber dimensions (1.5 in. by 3.5 in.) result in area of 5.25 square inches, section modulus (major axis) of 3.06 cubic inches, and moment of inertia (major axis) of 5.36 inches to the fourth power. Average truss lumber cross-sectional properties (table 1) closely agreed with those values, but deviated in individual specimens. Area ranged from 9 percent below to 6 percent above standard, section modulus from 12 percent below to 7 percent above, and moment of inertia from 15 percent below to 10 percent above. All the distributional characteristics were skewed toward lower measurements (figs. 4, 5, and 6). Variations in section properties directly affect variations in mechanical properties based on standard dimensions, area affects load capacity and stiffness in compression and tension, section modulus affects load capacity in bending, and moment of inertia affects bending stiffness.

Grade Class (GC)

All lumber used in this study had been grade stamped at mills according to visual stress grading rules. Much of it, however, had been conservatively rated. For example, many of the Southern Pine pieces grade-stamped No. 2 could have met all characteristics (warp, knot size, slope of grain, wane, and manufacturing imperfections) of Select Structural *(6)*. Consequently, the truss lumber was reevaluated for grade at Forest Products Laboratory (FPL).

Grade reevaluation followed grading agency rules for warp. For knots and slope of grain, however, reevaluations were based on values in American Society for Testing and Materials Standard ASTM D 245 *(1)* co ·esponding to limiting strength ratios of the National Grading Rule (NGR) *(6)* for softwood dimension lumber. While the NGR sets maximum knot sizes and slope of grain, the values are generally conservative relative to strength ratio limitations and ASTM D 245. Also, the 10 grade classes (table 2) developed, based on ASTM D 245, provide both closer estimates of strength ratio than could be done by the NGR and a nearly linear progression of median strength ratios, at about 10 times the GC number (classes 0 and 1 were exceptions).

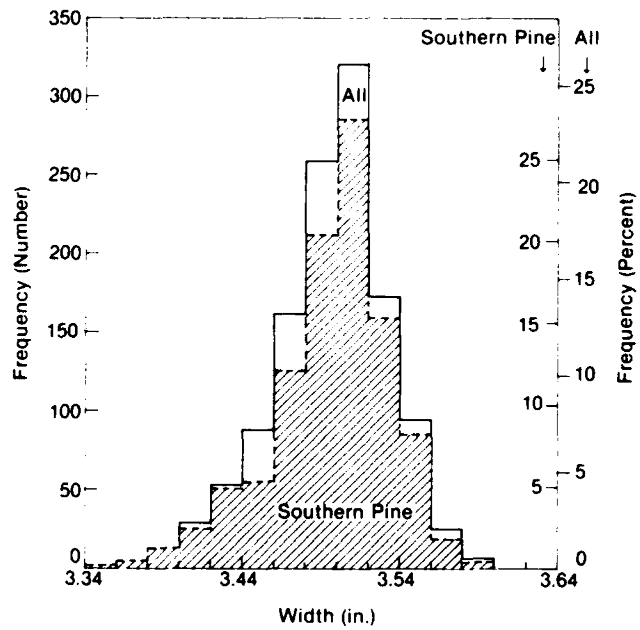

Figure 2.—Distribution of lumber width. (M152112)

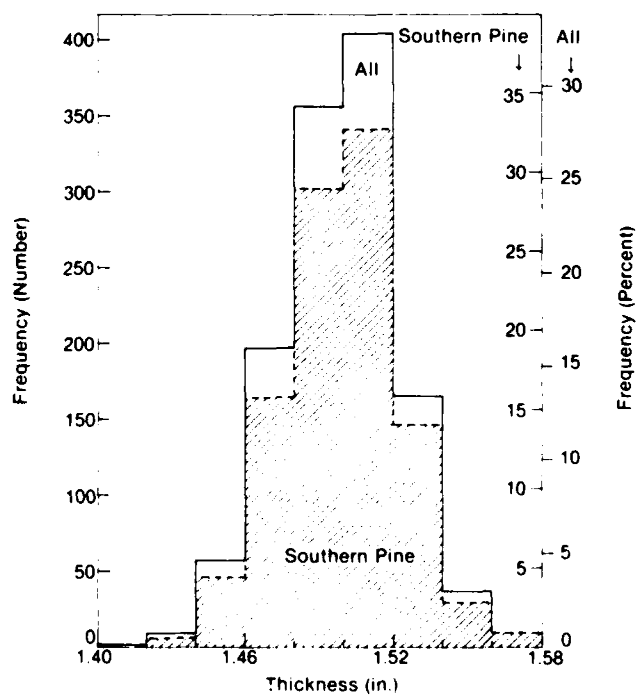

Figure 3.—Distribution of lumber thickness. (M152113)

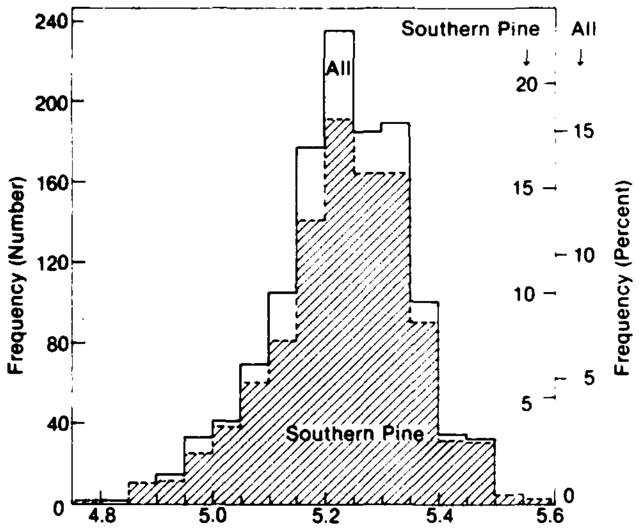

Figure 4.—Distribution of lumber cross-sectional area. (M152114)

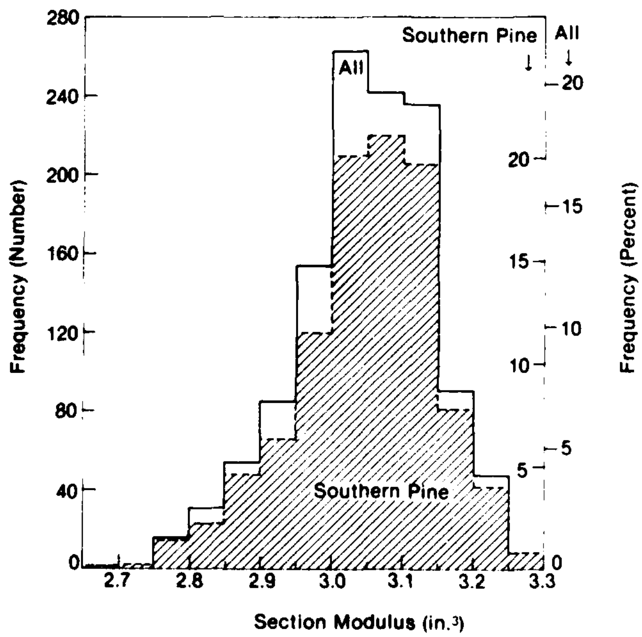

Figure 5.—Distribution of lumber section modulus (major axis). (M152115)

The data on warp and GC were used to reassign the lumber to NGR grades. Table 3 shows the tally of specimens as reassigned solely on the basis of either warp or knots and slopes of grain, with the mill grade stamp tally for comparison. Of the 704 specimens of truss lumber, 178 had been grade-stamped as No. 1 and 468 as No. 2. Yet, 570 specimens could have rated No. 1 or better due to knots and slope of grain, 618 could have rated No. 1 or better based on warp, only 22 would have rated No. 2 based on knots and slope of grain, and 59 would have rated No. 2 based on warp. Thus, the reader should recognize that the lumber obtained for this study was of generally higher quality than might have been obtained at another time, a different location, or under different marketing conditions.

Mechanical Properties

Strength tests in compression, tension, and bending (fig. 1) were conducted at standard rates of loading *(2)*. The compression test was full length with lateral support. The tension test was also full length except for the 2-foot gripped length on each end. Bending tests were either third-point loading on a span of 54⅜ inches or center-point loading (opposite direction from third point) on a span of 36¼ inches, both edgewise. Four times as many third-point tests were conducted per truss as for center-point tests. The types of bending tests and orientations shown in figure 1 were meant to simulate typical bending loads on W-truss chords.

Each type of strength test furnished load-deformation data for a specific type of static E—bending E (EB), tensile E (ET), and compressive E (EC). Also, before the cords were cut or strength tested, the full-span E (EF) was determined on each chord member in a flatwise dynamic bending test and the short-span E (ESP) was determined in an edgewise static bending test. ESP was determined with the same span and loading arrangement used for third-point bending strength tests. Depending on length, four to seven ESP tests were made per chord. Starting at one end of a chord, successive ESP test segments overlapped each other by 36¼ inches (two-thirds of the short span), thereby yielding a good profile of how ESP varied along the chord length.

Statistics on averages and COV's of strength and E, based on actual lumber dimensions, are given in table 4. Table 4 also includes data based on the minimum bending strength per chord. Used here, minimum means the lowest modulus of rupture of the bending strength tests per chord, based on the two third-point and one center-point tests for the top chord or the two third-point tests for the bottom chord. The

true minimum per chord cannot be guaranteed with the testing scheme used in this study, because the third-point bending test imposes maximum moment on the middle third length of its test span, and the center-point test only at its midspan, but the lowest moment capacity can occur at any point in the chord length. Thus, for a 14- foot top chord length, the chance of imposing the maximum moment on the weakest point is about 22 percent. This may partially explain why the minimum bending strengths averaged considerably higher than either compressive or tensile strengths (table 4), which reflect weakest points in chords.

Relation of Strength to Other Properties

As suggested by data plots (figs. 7 – 10, pp. 12 – 20), regression models may be useful for predicting strength properties of individual chord members. The data plots show strength of Southern Pine specimens in relation to the three types of MOE determined in this study and grade class. Data plots for all specimens were very similar. In plots with ESP, the minimum ESP per chord (ESPL) was used.

Some strength properties were found to be more closely related to E or grade class than other strength properties. For compression (fig. 7), the strength distribution showed a good increasing trend with any of the E, a desirable trait for machine stress rating, and a moderately good increasing trend with grade class which had a relatively small range. The tensile strength distributions (fig. 8) had more scatter, particularly for higher E, and a less well-defined increasing trend than those for compression. Although tensile strength tended to increase with E on average, the lower values of the tensile strength distribution appeared more or less constant over a considerable portion of the modulus range, particularly for EF. Thus, E seems a relatively poor discriminator of tensile strength unless ESP or ET are above about $1.2(10^6)$ pounds per square inch (psi) and EF is somewhat greater. Grade class does not appear to be a discriminator of tensile strength except for the two highest class numbers (fig. 8). For minimum bending strength per chord (fig. 9), the strength distribution showed as good a progression with ESP as did compressive strength, but with a broader range. Thus, ESP appears to be a good discriminator of the minimum bending strength per chord and would be useful for machine stress rating for bending strength. The minimum bending strength regression distribution on EF was similar to that on ESP, except the lower values in the distribution were spread over a broader range for EF than for ESP. The minimum bending strength distribution showed some progression with grade class for classes 5 through 9, similar to that for compressive strength. The bending strength distribution of individual specimens also showed good progression with EB, better for center point than for third point (fig. 10).

Simple regression equations of the form $Y = A + BX$ were fitted to the data shown in each plot (figs. 7–10), where Y = strength in compression, tension, minimum bending strength per chord, third-point bending strength, or center-point bending strength, and X = EF, ESPL, EC, ET, EB, or

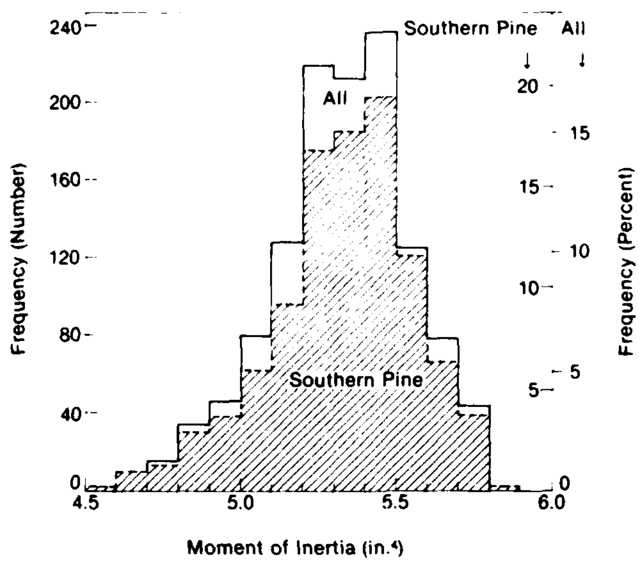

Figure 6.—Distribution of lumber moment of inertia (major axis). (M152116)

GC. Multiple regressions, $Y = A + BX_1 + CX_2$, were also fitted to the data where X_2 = GC. An additional multiple regression of the same form fitted strength on X_1 = ESPH (the highest ESP per chord) and X_2 = ER (the ratio of ESPL to ESPH per chord); this will be referred to as the E-ratio model. Results of regression calculations are shown in table 5, which includes data on standard deviation about the regression, S, and coefficient of determination, (r^2) as well as the regression coefficients, A, B, and C.

For compressive strength, the three types of MOE were all about equal in accounting for strength variation, about 60 percent as evident in the r^2's of table 5. While grade class by itself was a poor correlator with compressive strength ($r^2 = 0.2$), it did add significantly in the multiple regression with any of the three types of E, accounting for an additional 5 to 8 percent of the variation in strength. The E-ratio multiple regression accounted for about 63 percent of the variation in compressive strength, but it did not appear to be particularly better than the simple regressions with ESPL or EC.

Table 2.—GC limits on knots and slope of grain

GC	Lower limit of strength ratio	Median GC strength ratio	Maximum knot size[1]: Compression	Maximum knot size[1]: Bending and tension centerline knots	Maximum knot size[1]: Bending and tension edge knots	Worst slope of grain[1,2]: Compression	Worst slope of grain[1,2]: Bending and tension	NGR grade equivalent
	Pct	Pct	In.	In.	In.			
9	85	92½	⅝	⅝	5/16	1:13	1:18	Select Structural
8	75	80	—	—	½	—	1:15	Select Structural
			1	1	—	1:11	—	No. 1
7	65	70	—	—	¾	—	—	Select Structural
			—	—	—	—	1:11	No. 1
			—	—	—	1:8	—	No. 1
			1⅜	1⅜	—	—	—	No. 2
6	55	60	—	—	1	—	—	No. 1
			—	—	—	—	1:9	No. 2
			—	—	—	1:6	—	Construction
			1¾	1¾	—	—	—	No. 3
5	45	50	—	—	1 5/16	—	1:7	Construction
			2 3/16	2 3/16	—	1:5	—	No. 3
4	34	39½	2⅜	2⅜	1½	1:4	1:5	No. 3
3	26	30	—	—	1¾	—	1:4	No. 3
			2 9/16	2 9/16	—	1:3	—	Economy
2	19	22½	—	—	2	—	—	Standard
			2⅞	2⅞	—	1:2	1:3	Economy
1	9	14	—	—	2½	—	—	Standard
			3¼	3¼	—	1:0	1:0	Economy
0	0	4½	3½	3½	3½	1:0	1:0	Economy

[1] Based on ASTM D 245 (1).

[2] Strength ratios for slope of grain of 1:3 and worse are estimates.

Table 3.—Tally of lumber, based on American softwood lumber stress grade limitations and mill grading

NGR grade	Grade based solely on warp[1]	Grade based solely on knots and slope of grain	Mill-grade stamped: Southern Pine	Mill-grade stamped: Douglas-Fir-Larch[2]	Mill-grade stamped: Hem-Fir[2]	Mill-grade stamped: Spruce-Pine-Fir[3]
Select Structural	618	278	—	—	—	—
No. 1	—	292	[4]129	44	—	5
No. 2	59	22	[5]465	—	—	3
Construction	—	31	—	14	2	12
No. 3	17	53	2	—	—	—
Standard	—	2	—	2	14	12
Utility	—	13	—	—	—	—
Economy[6]	3	[7]13	—	—	—	—

[1] Data missing on seven specimens.

[2] Includes some Canadian lumber.

[3] Includes Canadian Spruce-Pine-Fir and similar species grouping from the United States.

[4] About 53 percent stamped Dense.

[5] About 25 percent stamped Dense.

[6] Not a stress grade.

[7] Includes six specimens due to cracks, heart shake, or end splits.

For tensile strength, ET was the best sole correlator (table 5), accounting for 45 percent of the tensile strength variation for the Southern Pine specimens and 49 percent for all specimens. As for compression, grade class was not a particularly good correlator of tensile strength by itself, but it did contribute significantly to the multiple regressions with E, accounting for an additional 13 to 20 percent of the tensile strength variation. The E-ratio model was not appreciably better as a correlator of tensile strength than any of the E's by themselves.

The E-ratio model, EF, and ESPL were about equal in accounting for variation in minimum bending strength per chord, about 45 to 49 percent (table 5). Again, grade class was not particularly good as a correlator of minimum bending strength but did contribute significantly in the multiple regressions with E, accounting for an additional strength variation of 4 to 6 percent.

EB was a reasonably good correlator with bending strength of individual specimens (table 5), accounting for about 54 percent of third-point bending strength and about 63 percent of center-point bending strength. Grade class accounted for an additional 6 or 7 percent of the third-point bending strength variation, but did not contribute any significance in the multiple regression with EB on center-point bending strength. The lack of significance of grade class for the latter may be due to the low probability that a grade-controlling characteristic will occur at the highest stressed portion of a specimen, that is, at the central load point in the center-point test.

Overall, the strength regressions showed the highest correlations for compression and the lowest for tension. This reflects the lower standard deviations about the regression for compression (table 5), but compressive strength also had the lowest variation overall (table 4).

Data plots of EC, ET, and EB on EF are given in Figure 11 (pp. 21 – 24) and the supporting regression statistics in table 6. EC and ET showed high levels of correlation with EF ($r^2 > 0.90$). EB and EF were less well correlated ($r^2 < 0.83$), probably because EF reflected properties of wood over the full chord length of the truss lumber, whereas EB reflected properties over less than one-half of a chord length.

Table 4.—Mechanical properties of the truss 2 by 4's[1]

Property	Southern Pine specimens			All specimens		
	Number of specimens	Average	COV	Number of specimens	Average	COV
			Pct			Pct
Compressive strength	148	4,400	25	176	4,390	25
Tensile strength	149	3,830	53	176	3,960	52
Bending strength						
Minimum per chord	299	7,300	38	352	7,200	37
Third point	598	8,480	35	704	8,330	35
Center point	147	10,110	29	175	9,930	30
EC	147	1.56	28	174	1.59	28
ET	147	1.59	30	174	1.62	29
E						
ESPL	596	1.48	28	704	1.49	28
Third point EB	592	1.69	26	698	1.68	26
Center point EB	145	1.56	25	173	1.55	25
EF	592	1.65	27	699	1.67	26

[1] Averages based on psi for strength and 10^6 psi for E.

Correlations of Bending Strengths Within Chords

Two ways to present correlations of the within-chord bending strengths are 1) by simple correlation coefficients for pairs of within-chord bending strengths, and 2) by frequency classification. The following tabulation shows correlation coefficients for within-chord pairs of bending strengths for the 176 upper chords and 176 lower chords.

Strength Comparison	*Correlation Coefficient*, r
UPPER CHORDS	
Inner-Middle	0.579
Inner-Outer	.600
Middle-Outer	.594
LOWER CHORDS	
Inner-Outer	.551

The inner-outer r's shown in the tabulation can be interpreted to mean that 30 to 36 percent of the variation of within-chord paired strengths can be accounted for by knowing the strength of one of the pairs, suggesting that the strength at one position in a chord does not necessarily define the strength of another position very accurately.

Table 5.—Regression of strength on E and GC[1,2]

Y	X_1	X_2	Southern Pine: Number of specimens	Southern Pine: A	Southern Pine: B	Southern Pine: C	Southern Pine: Standard deviation about regression	Southern Pine: r^2	All: Number of specimens	All: A	All: B	All: C	All: Standard deviation about regression	All: r^2
Compressive strength	EF	—	147	1,245	1,949	—	681	0.61	174	1,295	1,880	—	702	0.58
	ESPL	—	148	1,374	2,113	—	667	.62	176	1,334	2,110	—	670	.62
	EC	—	148	1,299	1,983	—	650	.64	176	1,365	1,900	—	678	.61
	GC	—	148	625	486	—	979	.19	176	652	481	—	963	.21
	EF	GC	147	−939	1,798	313	615	.68	174	−665	1,677	295	644	.65
	ESPL	GC	148	−515	1,943	274	618	.68	176	−285	1,912	245	628	.67
	EC	GC	148	−696	1,831	287	593	.70	176	−288	1,719	250	634	.66
	ESPH	ER	148	−1,209	1,867	2,825	659	.63	176	−1,246	1,867	2,830	664	.63
Tensile strength	EF	—	149	−717	2,823	—	1,622	.37	176	−954	3,018	—	1,594	.40
	ESPL	—	149	−625	3,049	—	1,611	.38	176	−845	3,234	—	1,553	.43
	ET	—	147	−774	2,904	—	1,516	.45	174	−988	3,069	—	1,468	.49
	GC	—	149	−159	593	—	1,749	.27	176	−39	589	—	1,740	.29
	EF	GC	149	−3,700	2,549	509	1,348	.57	176	−3,662	2,661	485	1,321	.59
	ESPL	GC	149	−3,064	2,606	459	1,400	.54	176	−2,790	2,681	408	1,375	.56
	ET	GC	147	−3,364	2,581	460	1,285	.61	174	−3,281	2,678	430	1,243	.64
	ESPH	ER	149	−3,648	2,702	[a]3,182	1,608	.39	176	−4,481	2,845	[b]4,002	1,563	.43
Bending strength, minimum per chord	EF	—	296	90	4,276	—	2,010	.47	349	180	4,148	—	1,971	.47
	ESPL	—	299	453	4,540	—	2,049	.45	352	500	4,429	—	1,979	.46
	GC	—	299	1,008	869	—	2,446	.22	352	1,856	740	—	2,422	.20
	EF	GC	296	−2,570	3,722	496	1,888	.53	349	−1,877	3,658	400	1,876	.52
	ESPL	GC	299	−1,996	3,906	470	1,946	.51	352	−1,333	3,894	366	1,904	.50
	ESPH	ER	299	−4,070	4,157	[c]4,413	2,017	.47	352	−3,789	4,104	4,089	1,940	.49
Bending strength, individual specimens														
Third point	EB	—	598	284	4,872	—	2,016	.54	704	159	4,867	—	1,964	.55
	EB	GC	598	−3,025	4,228	575	1,857	.61	704	−2,416	4,236	479	1,838	.61
Center point	EB	—	147	1,054	5,817	—	1,820	.61	175	639	6,014	—	1,746	.65
	EB	GC	147	−273	5,525	[d]228	1,805	.62	175	−540	5,777	[e]198	1,735	.65

[1] For E in 10^6 psi.

[2] Each variable significant at the 0.01 percent level or better, except for coefficients with "a" (1.3% level), "b" (0.03% level), "c" (0.02% level), "d" (6.4% level, not significant), and "e" (7.6% level, not significant).

Table 6.—Regression of static E on dynamic E[1]

Model	N	A	B	Standard deviation about regression	r^2
		SOUTHERN PINE			
EC = A + B (EF)	147	0.006	0.962	0.130	0.91
ET = A + B (EF)	147	−.067	1.032	.125	.93
EB = A + B (EF)					
Third point	592	.196	.881	.217	.76
Center point	145	.237	.777	.165	.82
		ALL			
EC = A + B (EF)	174	−.002	.968	.127	.92
ET = A + B (EF)	174	−.083	1.047	.128	.93
EB = A + B (EF)					
Third point	698	.183	.883	.212	.77
Center point	173	.230	.772	.163	.82

[1] For E in 10^6 psi.

Table 7.—Frequency of lower chord bending strength (in psi) for 176 chords—two-way classification

Inner strength class	Outer strength class						
	2,000 to 3,999	4,000 to 5,999	6,000 to 7,999	8,000 to 9,999	10,000 to 11,999	12,000 to 13,999	14,000 to 15,999
0 to 1,999	—	—	—	1	—	—	—
2,000 to 3,999	4	3	3	2	—	1	—
4,000 to 5,999	1	11	14	4	2	—	—
6,000 to 7,999	4	9	11	12	7	—	—
8,000 to 9,999	—	4	4	15	7	1	1
10,000 to 11,999	—	2	8	10	10	5	3
12,000 to 13,999	—	—	1	—	3	7	2
14,000 to 15,999	—	—	—	—	—	2	1
16,000 to 17,999	—	1	—	—	—	—	—

Table 7 presents within-chord correlations for lower chords by two-way frequency classification, and table 8 shows them for upper chords by three-way frequency classification. The three-way classification of table 8 is necessary because of the three bending strength tests per upper chord.

Table 7, easier to evaluate than table 8, shows a central tendency in that the larger cell frequencies tend to lie on or near the diagonal cells for equal inner and outer strength classes. Thus, table 7 supports the concept that the two bending strengths for a lower chord member tend to be approximately equal, but that the two strengths can be quite different for some chords. For example, 15 of the chords had both inner and outer strengths that ranged between 8,000 and 10,000 psi; however, another chord had an outer strength in that range but an inner strength ranging between 0 and 2,000 psi.

Table 8 shows similar trends to those in table 7, except that cell frequencies for the inner- and outer-strength classes in table 8 are considerably diluted by the middle-chord strength classification. Thus, the central tendency for all three strength values for an upper chord to be approximately equal is not very obvious. Also, several cells in table 8 indicate that the strength of one portion of an upper chord was less than one-half the strength of another portion of the chord. The first cell shown (middle-strength class = 0 to 1,999 psi) is an example of an even wider discrepancy in strength, but the chord represented by that cell was not typical because it arrived at the Forest Products Laboratory broken at midlength. Such a chord would obviously be discarded during truss manufacture.

Table 8.—Frequency of upper chord bending strength (in psi) for 176 chords—three-way classification

Middle strength class	Inner strength class	Outer strength class								
		0 to 1,999	2,000 to 3,999	4,000 to 5,999	6,000 to 7,999	8,000 to 9,999	10,000 to 11,999	12,000 to 13,999	14,000 to 15,999	16,000 to 17,999
0 to 1,999	8,000 to 9,999	—	—	—	—	1	—	—	—	—
2,000 to 3,999	4,000 to 5,999	—	—	—	1	—	—	—	—	—
	6,000 to 7,999	—	—	1	—	—	—	—	—	—
4,000 to 5,999	2,000 to 3,999	1	1	—	1	—	—	—	—	—
	4,000 to 5,999	—	1	5	—	—	—	—	—	—
	6,000 to 7,999	—	1	3	—	—	—	—	—	—
	8,000 to 9,999	—	—	—	—	—	1	—	—	—
	10,000 to 11,999	—	—	1	1	—	—	—	—	—
6,000 to 7,999	4,000 to 5,999	—	4	2	4	2	—	—	—	—
	6,000 to 7,999	—	2	2	2	3	—	—	—	—
	8,000 to 9,999	—	1	2	3	—	1	—	—	—
8,000 to 9,999	2,000 to 3,999	—	—	1	—	—	—	—	—	—
	4,000 to 5,999	—	1	2	4	2	—	—	—	—
	6,000 to 7,999	—	1	2	5	4	1	—	—	—
	8,000 to 9,999	—	1	3	2	1	4	—	—	—
	10,000 to 11,999	—	—	—	1	4	—	—	—	—
	12,000 to 13,999	—	—	—	—	—	1	3	—	—
10,000 to 11,999	2,000 to 3,999	—	—	1	—	—	1	—	—	—
	4,000 to 5,999	—	—	2	3	2	—	—	—	—
	6,000 to 7,999	—	—	—	5	5	3	—	—	—
	8,000 to 9,999	—	—	—	2	3	3	—	—	—
	10,000 to 11,999	—	—	—	2	2	1	1	—	—
	12,000 to 13,999	—	—	—	—	3	—	—	1	—
12,000 to 13,999	4,000 to 5,999	—	—	—	1	—	—	—	—	—
	6,000 to 7,999	—	—	—	—	2	4	—	—	—
	8,000 to 9,999	—	—	—	2	1	—	3	1	—
	10,000 to 11,999	—	—	2	2	1	4	3	—	—
	12,000 to 13,999	—	—	1	—	1	2	1	—	—
14,000 to 15,999	10,000 to 11,999	—	—	—	—	1	2	1	—	—
	12,000 to 13,999	—	—	—	1	1	3	1	—	1
	14,000 to 15,999	—	—	—	—	—	—	—	1	1
16,000 to 17,999	10,000 to 11,999	—	—	—	1	—	—	—	—	—
18,000 to 19,999	16,000 to 17,999	—	—	—	—	—	—	—	1	—

Conclusions

Truss lumber sampled from fabricators in Illinois had dimensional characteristics at 12 percent moisture content that averaged very close to those for the standard size of nominal 2 by 4's. The distributions of those characteristics, however, tended to be skewed toward lower measurements, with variations that may affect compressive and tensile strength up to 9 percent, bending strength up to 12 percent, and E up to 15 percent.

Since mill grading of the lumber specimens was generally conservative compared to optimum grading based on the NGR limitations, strength results from this study may be different from those that might have been obtained under different lumber marketing conditions.

Relations of strength in compressior tension, or bending on ESP appeared adequate for strength prediction or machine stress rating. ESP accounted for 38 to 62 percent of the strength variation, depending on loading mode. EF was about equal to ESP in accounting for strength variation, but the lower values in the strength distributions were not as well behaved as for ESP. GC, a function of lumber strength ratio, was inferior to E as a predictor, but it did contribute significantly in multiple regressions with E, accounting for an additional 4 to 20 percent of strength variation.

The two or three short-span bending strengths measured at different positions in a specimen showed low correlation, suggesting that the bending strength at one position in a specimen can be quite different from that at another position.

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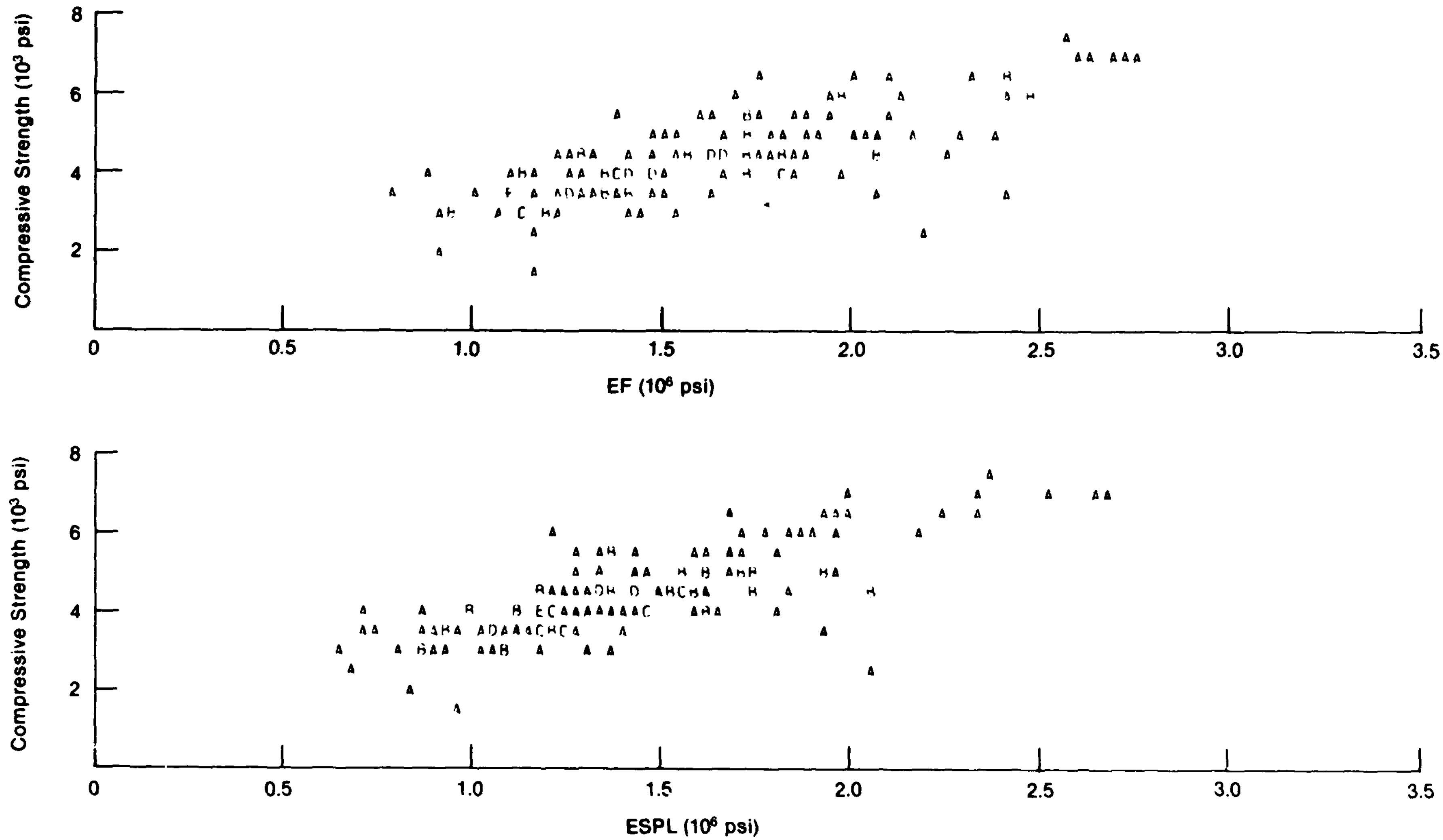

Figure 7a.—Data plots of compressive strength on EF and ESPL. A = 1 observation, B = 2 observations, etc. (M152117, M152118)

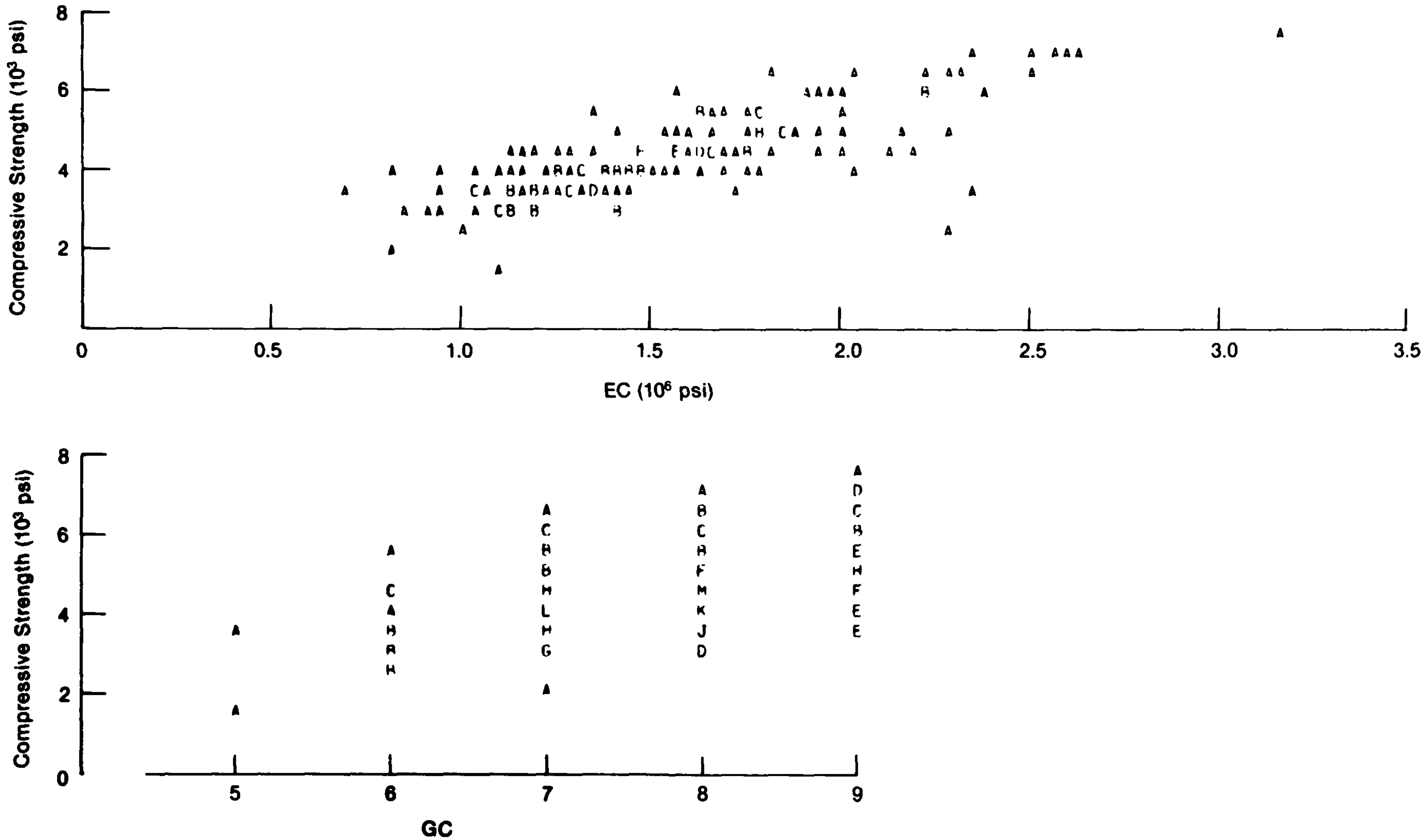

Figure 7b.—Data plots of compressive strength on EC and GC. A = 1 observation, B = 2 observations, etc. (M152119, M152120)

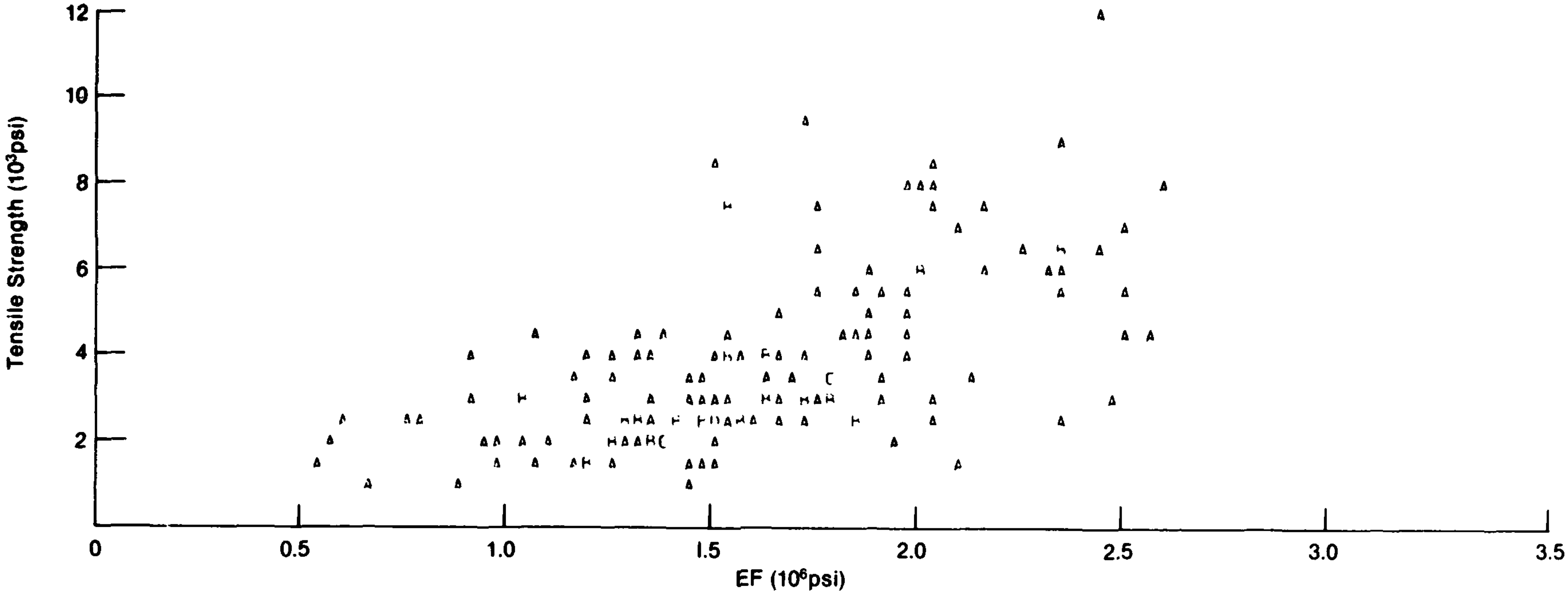

Figure 8a.—Data plots of tensile strength on EF. A = 1 observation, B = 2 observations, etc. (M152121)

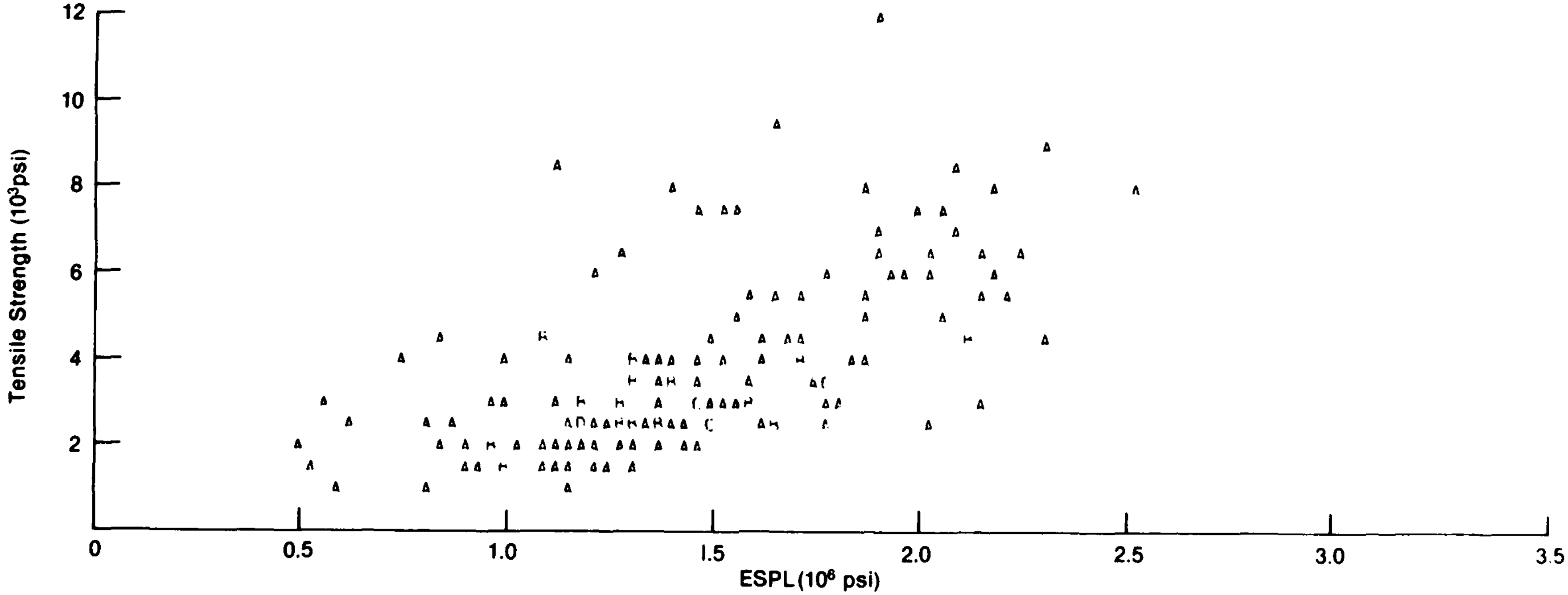

Figure 8b.—Data plots of tensile strength on ESPL. A = 1 observation, B = 2 observations, etc. (M152122)

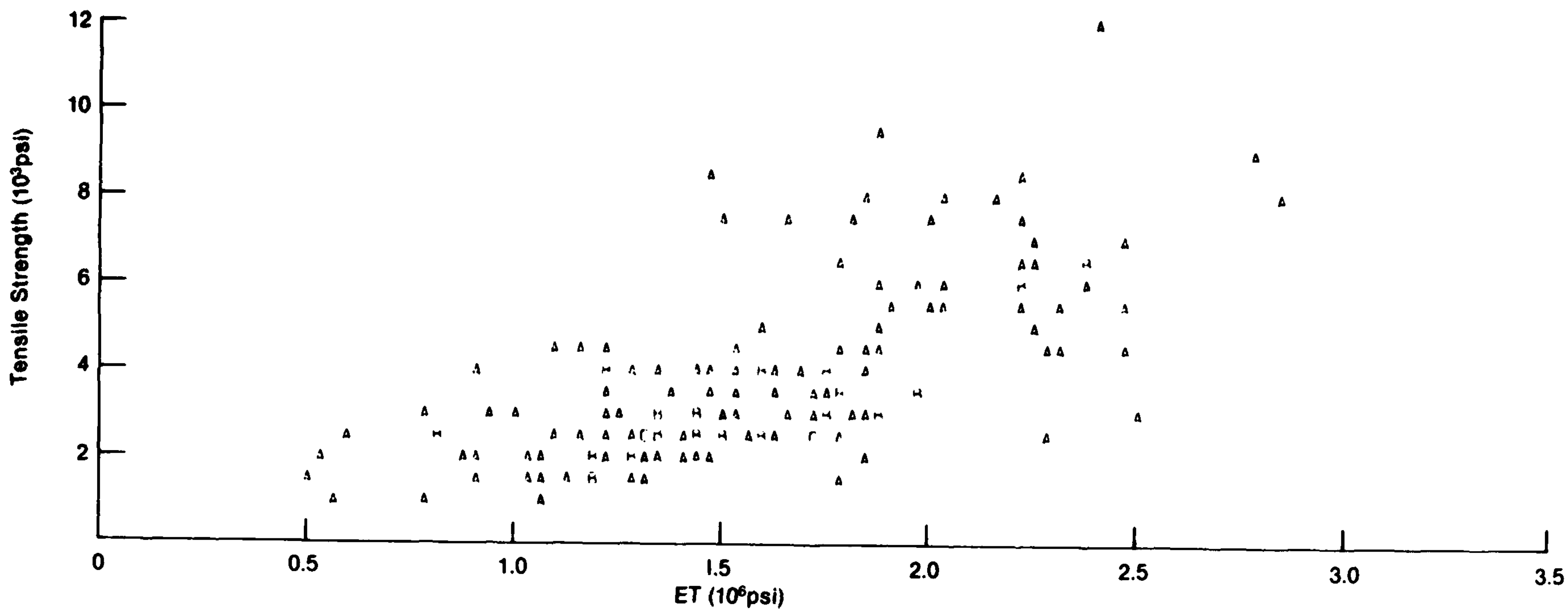

Figure 8c.—Data plots of tensile strength on ET. A = 1 observation, B = 2 observations, etc. (M152123)

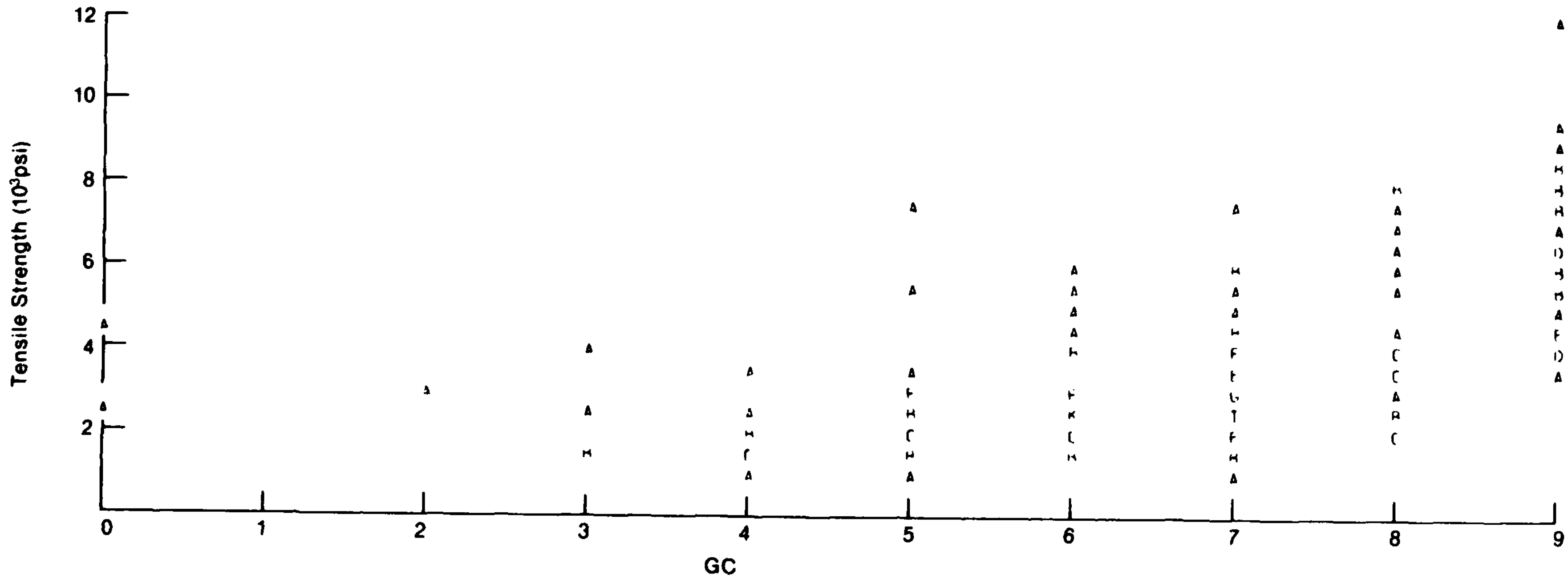

Figure 8d.—Data plots of tensile strength on GC. A = 1 observation, B = 2 observations, etc. (M152124)

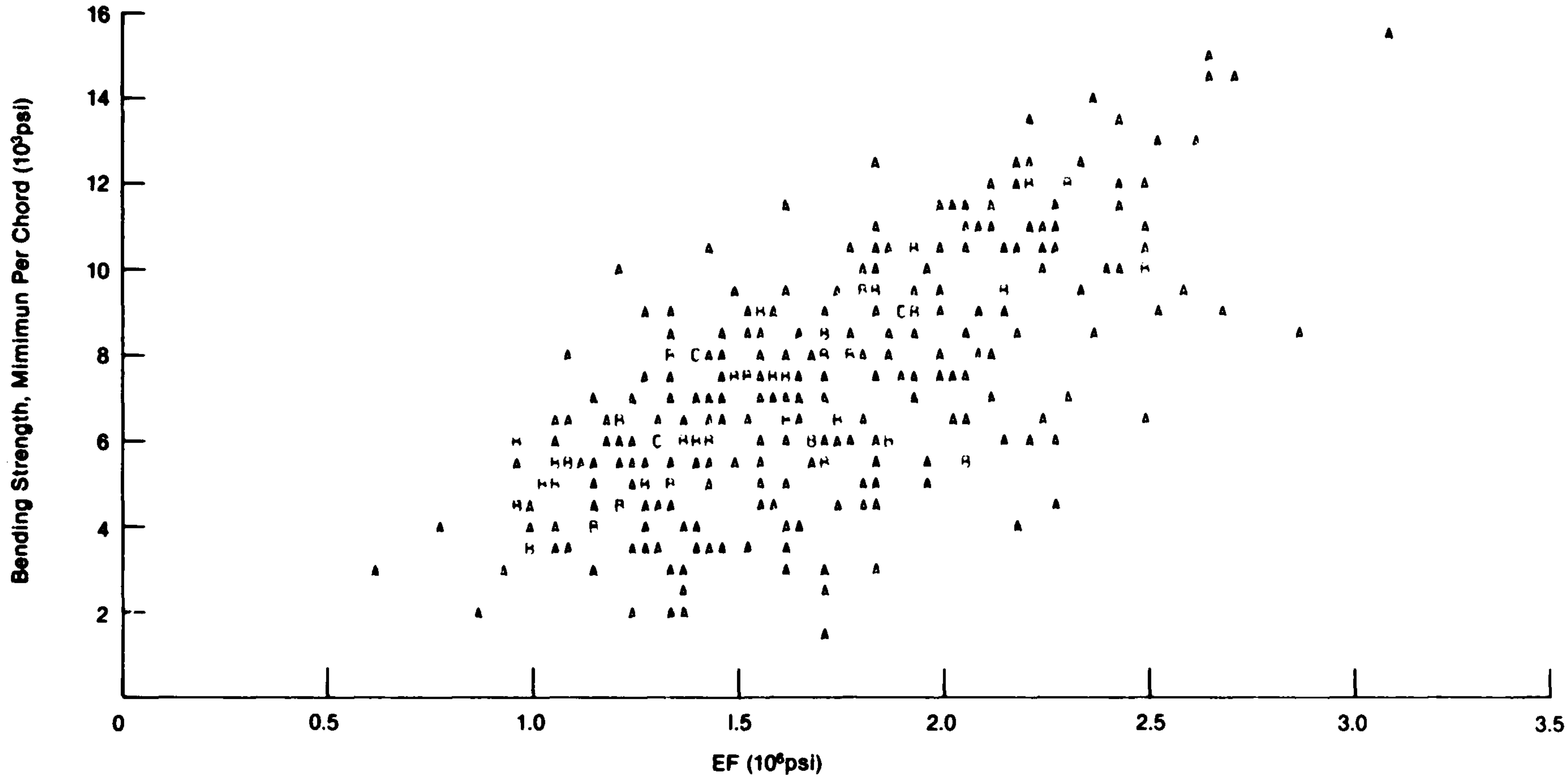

Figure 9a.—Data plots of minimum bending strength per chord on EF. A = 1 observation, B = 2 observations, etc. (M152125)

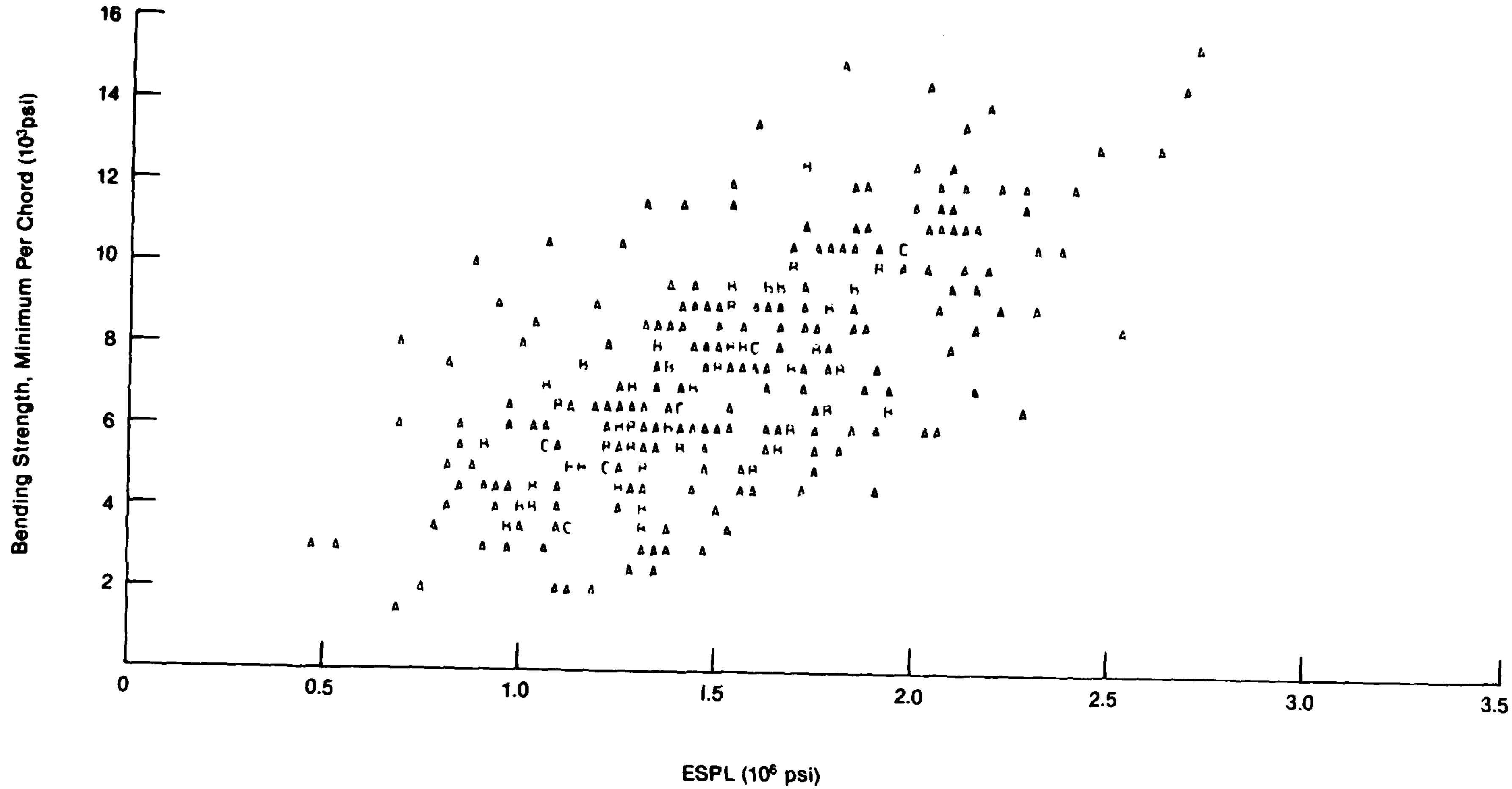

Figure 9b.—Data plots of minimum bending strength per chord on ESPL. A = 1 observation, B = 2 observations, etc. (M152126)

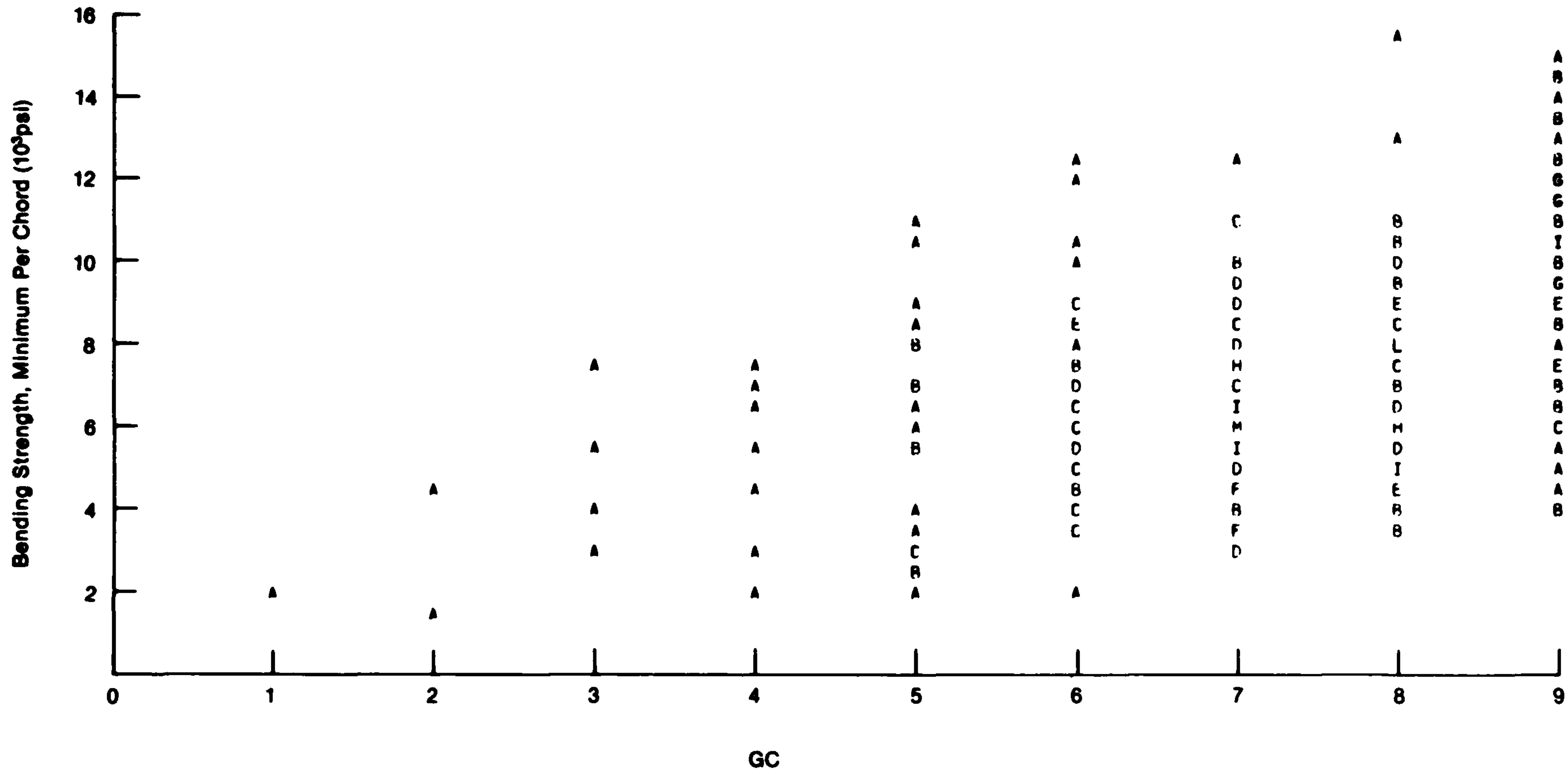

Figure 9c.—Data plots of minimum bending strength per chord on GC. A = 1 observation, B = 2 observations, etc.
(M152127)

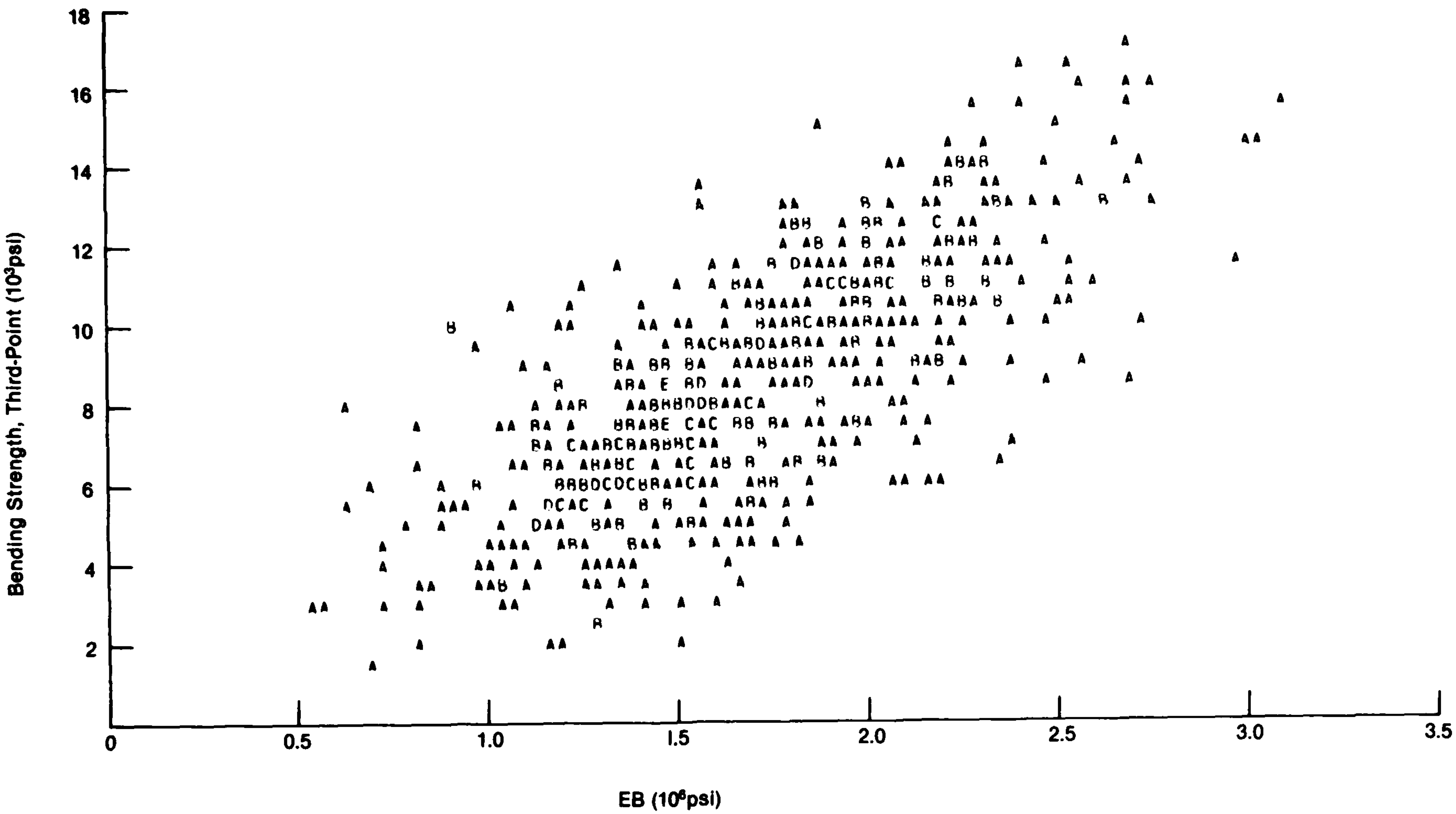

Figure 10a.—Data plots of third-point bending strength on EB. A = 1 observation, B = 2 observations, etc. (M152128)

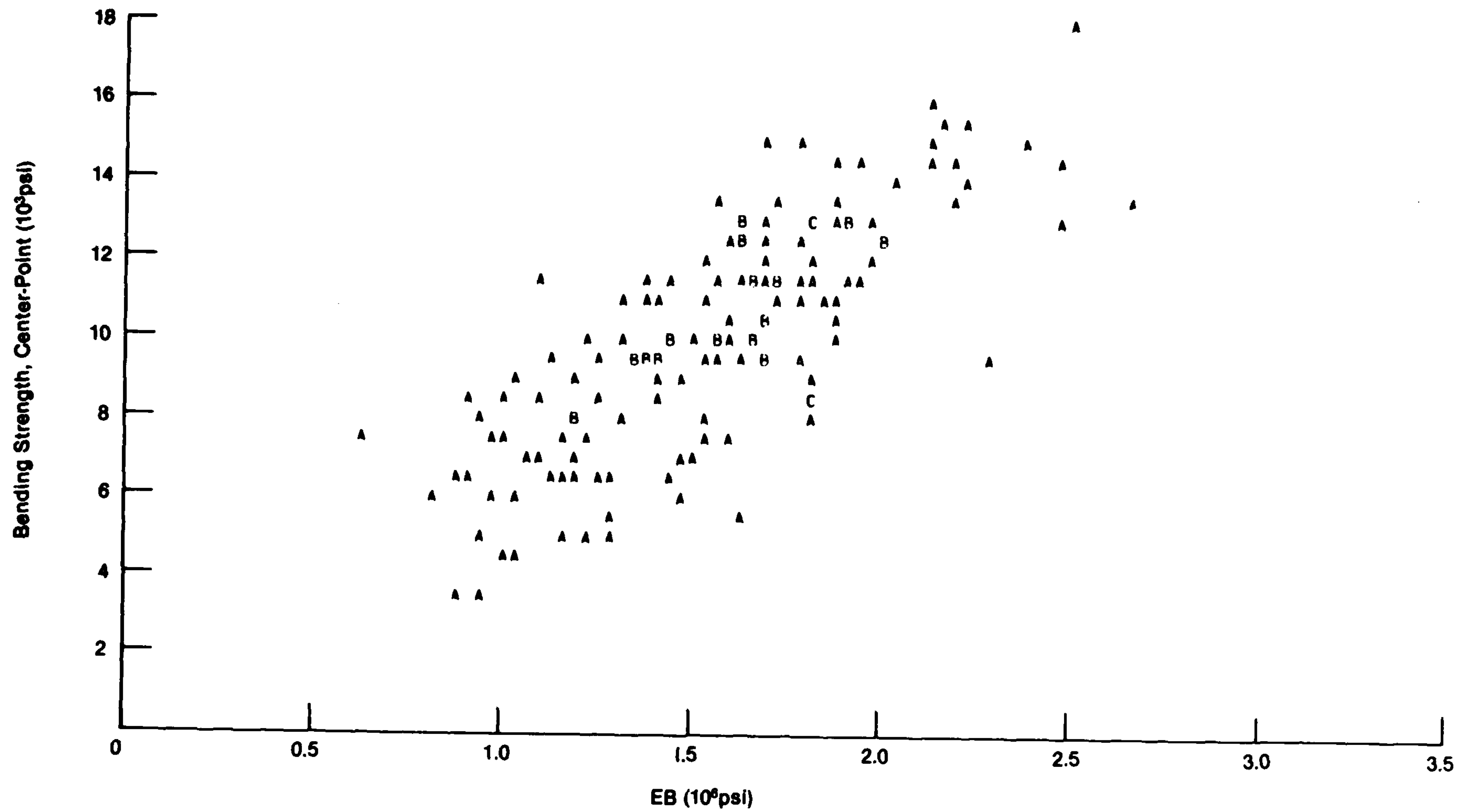

Figure 10b.—Data plots of center-point bending strength on EB. A = 1 observation, B = 2 observations, etc. (M152129)

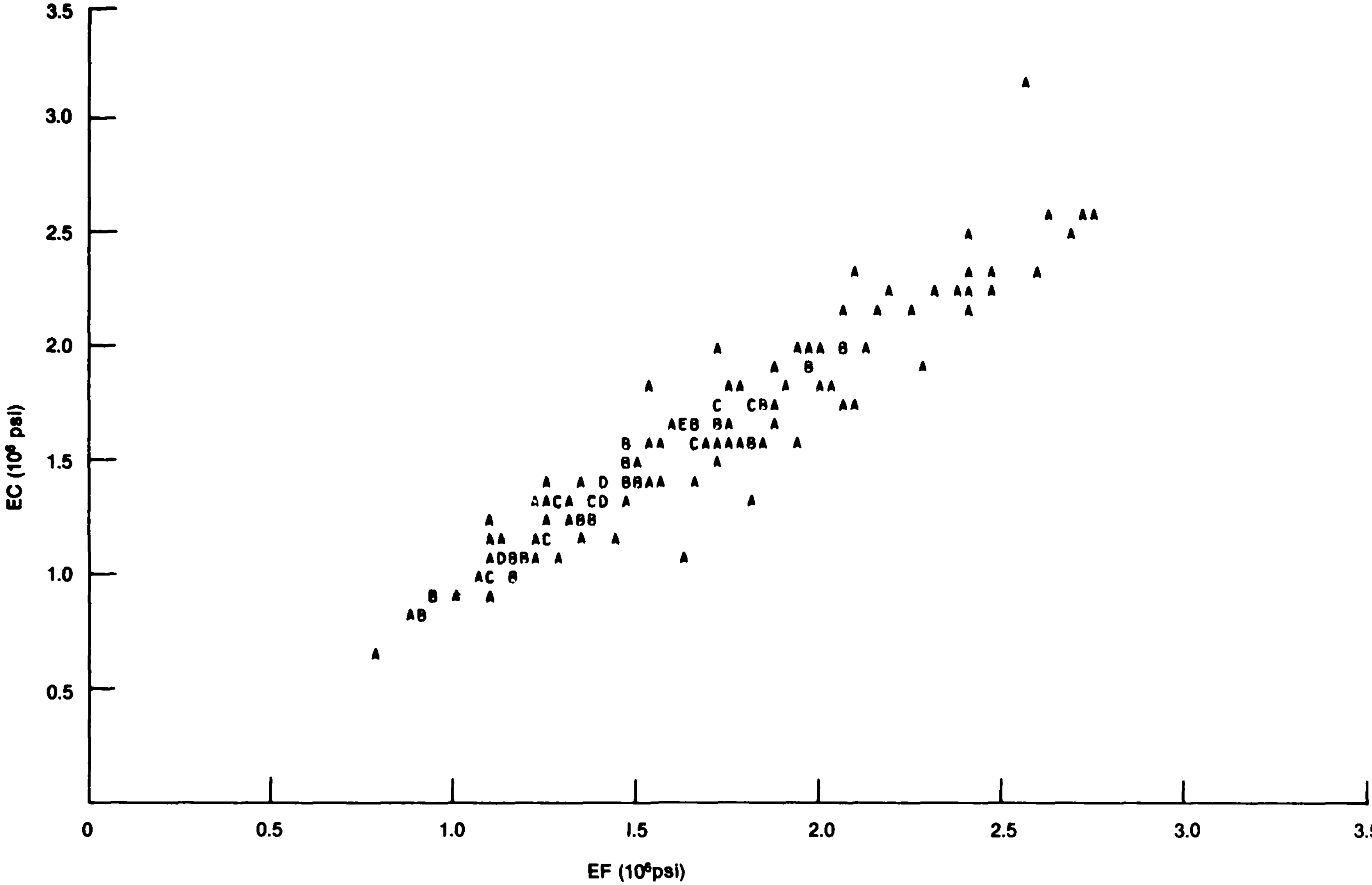

Figure 11a.—Data plots of EC on EF. A = 1 observation, B = 2 observations, etc. (M152130)

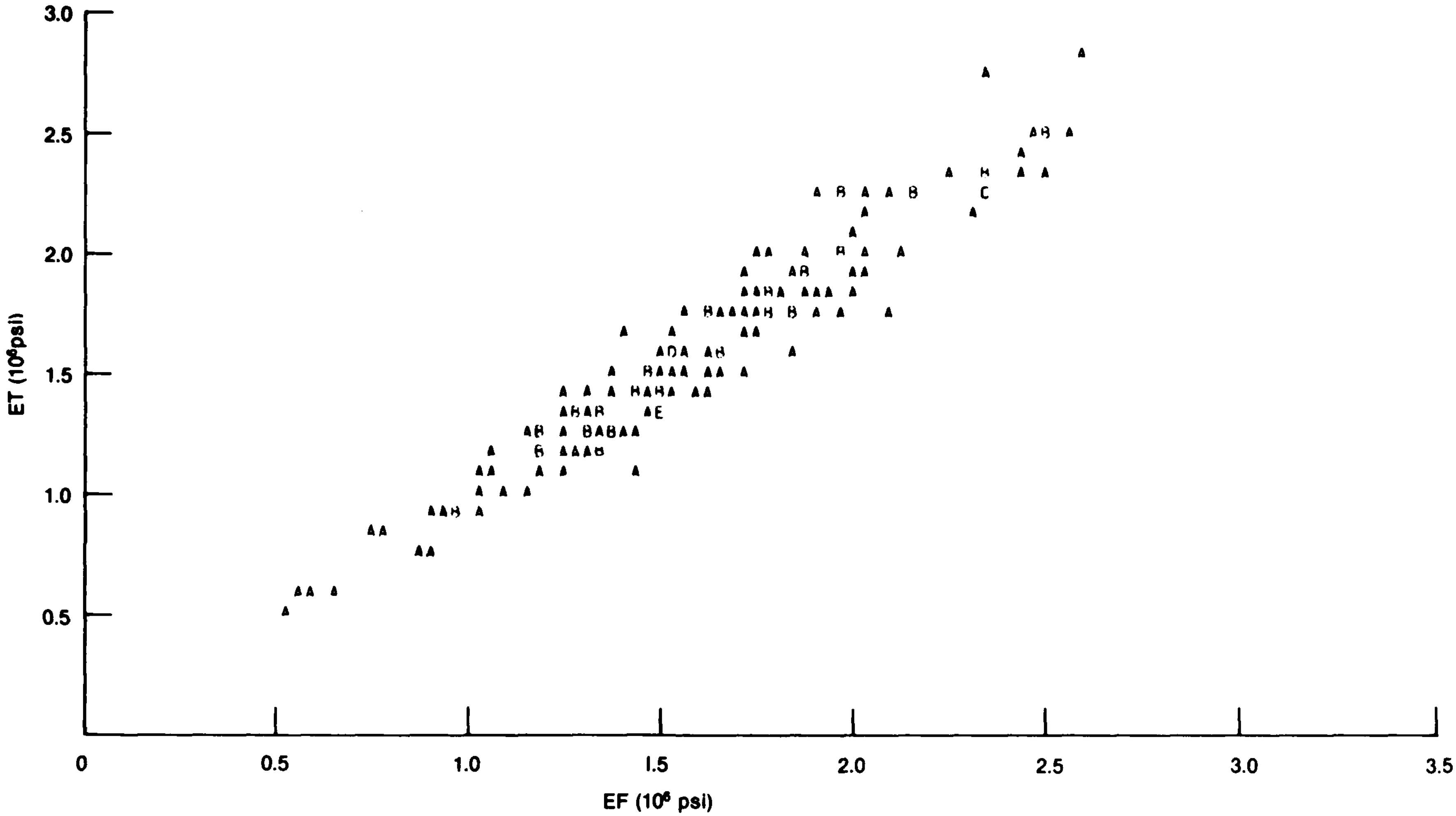

Figure 11b.—Data plots ET on EF. A = 1 observation, B = 2 observations, etc. (M152131)

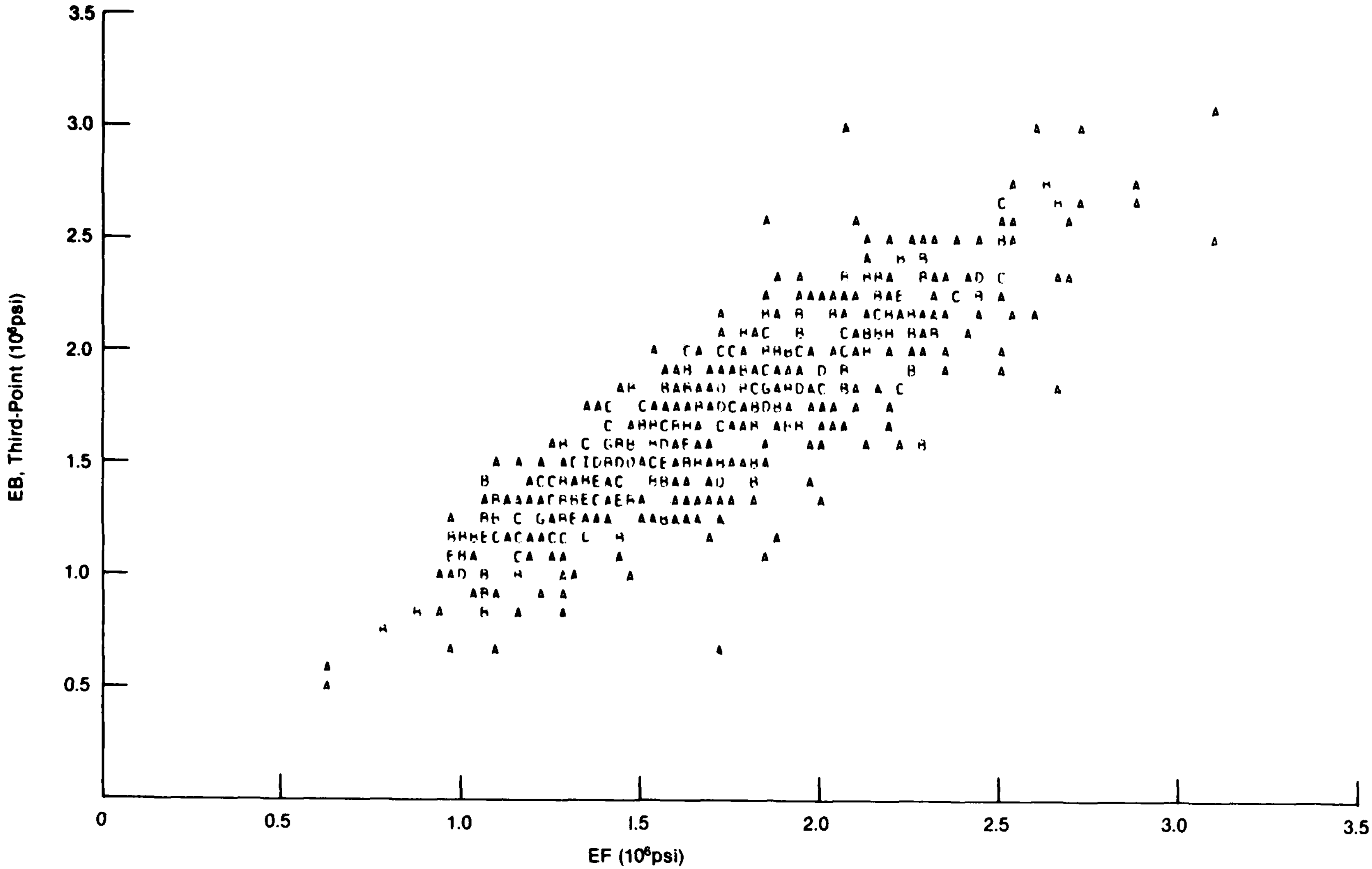

Figure 11c.—Data plots of EB, third-point, on EF. A = 1 observation, B = 2 observations, etc (M152132)

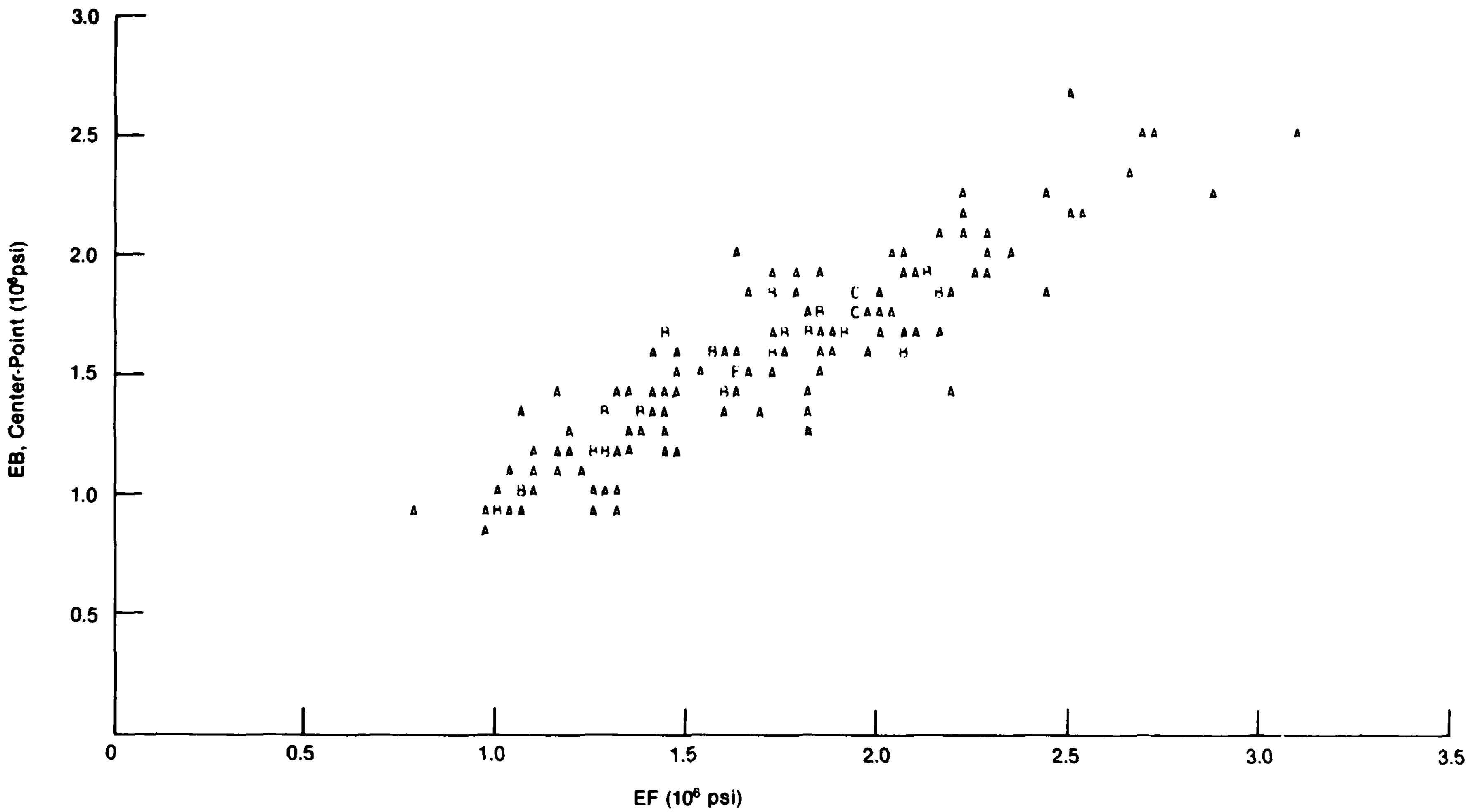

Figure 11d.—Data plots of EB, center point, on EF. A = 1 observation, B = 2 observations, etc. (M152133)

Gerhards, C. C.; Characterization of physical and mechanical properties of 2 by 4 truss lumber; USDA Forest Serv. Res. Pap. FPL-431, 24 p., Madison, WI: Forest Products Laboratory; 1983.

This paper summarizes data on dimensional characteristics, optimum grade, and regressions of strength on modulus of elasticity and grade class (a function of strength ratio) of lumber specimens sampled from truss fabricators in Illinois. The two or three measures of bending strength at different positions in a specimen showed low correlation, suggesting that bending strength at one position in a specimen can be quite different from that at another position.

KEYWORDS: Physical properties, Mechanical properties, 2 by 4's, truss lumber, bending, tension, compression, strength, modulus of rupture, modulus of elasticity, moisture content, grade, width, thickness, distributions, regressions